5236-101XZ

UNDERWATER IMAGING SYSTEM

BACKGROUND OF THE INVENTION

This application is a continuation-in-part of Application Serial No. 07/781,038, filed October 21, 1991, now abandoned.

6/5/95

This invention relates generally to an imaging system for detecting a target in a turbid medium. More particularly, this invention relates to a system for detecting an underwater target using lidar.

Several techniques have evolved over the years for overcoming the problems associated with detecting targets in a light scattering medium. One technique utilizes a narrow beam from a pulsed laser, such as a doubled YAG, to scan the ocean. Generally, the beam transmitter and the receiver aperture, which must be quite large to collect sufficient energy, are scanned together, using scanning mirrors or other devices such as prisms. The energy received from each pulse is detected with a photomultiplier, or similar quantum-limited device, and the resulting signal is amplified with a logarithmic response amplifier, digitized, and then processed. Because the pulses are short, typically 10 nanoseconds, the detection electronics must be very fast, digitizing at 200 MHz or faster. Since the pulse rate is low, the processing rates required to analyze the data from each pulse are within the state of the art. Such methods require the use of mechanical scanners that are slow and difficult to build, particularly if they are to be mounted on aircraft. In accordance with a primary advantage of

the present invention, the need for fast digitizing electronics and mechanical scanners is eliminated.

Another technique is range gating, which utilizes a pulsed flood beam and a number of gated image intensifiers with charge-coupled devices (CCD's). The intensifiers are gated on when the beam pulse reaches a specific depth. Typically, the gate is applied just as the pulse beam that encounters the object returns to the receiver so that the full reflected return is obtained. A second intensifier is gated on a little later to detect the shadow of the object. The image of the target is obtained by taking the difference of the two images which then eliminates the sea water backscatter and enhances the target signature.

There are numerous drawbacks associated with the range gating technique. Specifically, range gating does not allow utilizing all, or substantially all, of the information returned from each pulse to create three-dimensional data sets. Rather, in such prior art systems, a volume of the medium is illuminated and by range gating, a specific section of the illuminated medium is selected. Thus, the signal above and below the range gate is rejected. Consequently, of the energy transmitted into the volume of the medium, only a small amount of the return is used. Additionally, a three-dimensional data set cannot be created from a single pulse. Rather, three-dimensional information can only be obtained by collecting many pulses, during which time the aircraft, or other vehicle must remain stationary. A large multiplicity of shots is required to create an image, thus wasting energy from the laser.

Despite the availability of such

techniques, existing lidar systems are limited by the size of the receiver optics that can be used in a scanner. Generally, the light reflected from targets which are deeply submerged or are submerged in a very turbid medium is weak. Although large aperture optics can aid in maximizing the amount of light collected from weak returns, the size of the optics that can be used in a scanner is restricted by the size of the moving prisms or mirrors. Such cumbersome mechanisms can be eliminated, as in the present invention, by utilizing the motion of a vehicle, a boat or an aircraft carrying the system so that the dimensions for scanning can be reduced to one. However, the scanning problem is still formidable and restricts the size of the apertures that can be used. Moreover, volume scanning systems are very expensive, and require considerable power and weight. Consequently, the ability to install such systems in aircraft or other vehicles is restricted.

Furthermore, those systems which utilize range gating, instead of volume scanning, suffer from poor range resolution and area coverage. When the target is at a different depth than expected, the target return will be subtracted as well as the background, and poor performance results. Additionally, very large pulse energies are required to obtain sufficient signal-to-noise ratios to detect objects at even moderate depths.

What is needed is an imaging system which provides an accurate and reliable image of an underwater target, eliminates the problems associated with mirror scanning and utilizes all, or substantially all, of the information returned from each pulse to eliminate wasting energy from the

laser.

The preceding and other shortcomings of prior art systems are addressed and alleviated by the present invention which provides a system which can penetrate a turbid medium over a considerable slice (width) without scanning or requiring fast electronic devices.

SUMMARY OF THE INVENTION

The present invention provides an imaging system for detecting a target in turbid medium, such as water or air. The system includes a means for generating a periodic series of discrete pulse beams in the shape of fan beams, each of which are substantially uniform in intensity, or with greater amounts of energy at the ends of the fan to compensate for losses due to the greater distance, to illuminate sections of the medium.

In operation, a single pulse beam is emitted to illuminate a section of the medium. A large aperture optic collects the back reflected portions of the pulse beam and focuses the reflected portions on a field-limiting slit. The field-limiting slit, located in front of the photocathode, rejects multiply reflected light. A lens, positioned between the field-limiting slit and the photocathode, reimages the image on the field-limiting slit onto the photocathode. Coupled to the streak tube is an imaging detector, typically a CCD, which detects signals generated by the streak tube in response to the reflected portions of the pulse beam impinging on the photocathode. Other imaging detectors, such as a TV camera or photodiode array may also be used To obtain a volume display of the medium, the generating means is moved normal to the

longitudinal axis of the pulse beam so that each pulse illuminates adjacent sections of the turbid medium. A volume display of the medium is thus generated by combining the returns from adjacent sections of the medium. All, or substantially all, of the light returned from each pulse is utilized.

The photocathode on the streak tube is a thin strip behind a field-limiting slit on which the illuminated strip of the ocean, or scattering medium, is imaged by the receiver optics. When the laser beam pulse, typically a few nanoseconds in duration, returns to the receiver from the surface of the water, the electronic sweep of the tube is initiated, so that the following time history of the returning signal spread across the lateral surface of the tube anode is then a record of the reflection from the medium itself and from any submerged bodies in the medium, such as mines or submarines, including the reflection from the top surface of such objects and of the shadow below them. Because the slit cathode is long and covers the width of the ocean illuminated by the fan-shaped beam from the laser, the image on the anode phosphor or area detector is a wide vertical section of the ocean. In addition to imaging objects immersed and floating in the medium, the invention also applies to imaging objects on the bottom and to obtaining a profile of bottom topography that may be the only way to distinguish silt covered objects, such as archaeological remains lying on the bottom, from the bottom itself.

The invention described herein can be employed, for example, from a fixed wing aircraft or helicopter, from boats on the water surface, or from submerged vehicles for search at great depths. The

invention is not exclusively restricted to use on oceans or lakes, but is useful in probing the contents of any turbid media through which light can pass, even if absorbed and scattered, as long as some return can be obtained. For example, the invention can be used to detect a target in air. The items described in the following description are applicable to water probing, but there is no reason that the concept cannot be applied to the analysis of smaller volumes using very short laser pulses, picoseconds duration for example, since the streak tube can capture such time intervals.

The image on the anode can be photographed by means of a CCD camera or similar device, particularly by logarithmic area array CCD-like detectors, which is read out slowly compared to the fast duration of the returning signal. The anode can also be replaced by a thinned backside illuminated CCD. This enables one to view the phenomena on a cathode ray screen directly, or after encoding the signal, to enable one to process such images to obtain enhanced imagery through various means common to those versed in the art of enhancement, such as subtracting the mean return from the recorded ocean section. The subsequent display of such ocean sections can be manipulated by adding many sections together to provide a three-dimensional view of the underwater scene. Such three-dimensional data sets, obtained by moving the sensor system normal to the fan beam between each exposure so that each section is from an adjacent section of the ocean, provide the ability to enhance detection and reduce false alarms by rejecting images, such as fish, that might not be apparent in any single section image. All of the light returned

is utilized in creating three-dimensional data sets, thus not wasting energy from the laser.

The foregoing and additional features and advantages of this invention will become further apparent from the detailed description and accompanying drawing figures that follow. In the figures and written description, numerals indicate the various features of the invention, like numerals referring to like features throughout for both the drawing figures and the written description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic showing of an aircraft employing the present invention to view objects underwater;

FIG. **2** is a block diagram of the preferred embodiment of the invention;

FIG. 3~~(a) - 3(c)~~ is a timing diagram of signals obtained from use of the preferred embodiment in the system of FIG. **1**;

FIG. **4** is a diagram of the beam distribution on the MCP, phosphor and CCD;

FIG. **5** is a schematic diagram of the laser and the projection optics of the preferred embodiment shown in FIG. **2**; and

FIG. **6** is a schematic diagram of the detection system of the preferred embodiment shown in FIG. **2**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention provides a system for detecting targets located in a light reflecting medium, such as water. The system can be utilized to observe a water interface, the structure of the medium including the distribution of particulate matter or suspended bodies, a bottom profile, and objects included in any of these. More particularly, the invention can be used to detect targets in any medium through which light can pass, even if absorbed and scattered, as long as some substantially directly reflected light can be obtained. For example, the system can be used to detect a target in air.

The system includes a light source for producing a series of discrete pulse beams which have a modified non-uniform intensity distribution to produce uniform signal-return. The reflected portions of the pulse beam are received by a detection system comprising receiving optics, a streak tube and an imaging area detector. In operation, the invention is mounted on a vehicle adapted for movement over the target area. A light source emits periodic, narrow, fan-shaped pulse beams to illuminate a succession of thin-slices of the turbid medium.

The detection system includes a light collecting optic, a field-limiting slit, a streak tube and an imaging area detector. The light collecting optic collects reflected light and images it on a field-limiting slit, which rejects multiply scattered light. A lens, disposed between the field-limiting slit and a photocathode on a streak tube, focuses the image on the field-limiting slit onto the photocathode. Because of the narrow fan-

shaped illumination and the field-limiting slit at the cathode, the light collected is substantially directly reflected light, and not light multiply reflected by the medium, thus providing improved image contrast.

To collect the maximum amount of light from weak returns, the aperture of the optic should be as large as possible. The photocathode on the streak tube, however, should be sufficiently large to encompass the image of the fan beam illuminated volume.

Inside the streak tube, the photoelectrons emitted from the photocathode are accelerated and then electrostatically focused on the phosphor layer or anode of the streak tube. On passage from the cathode to the anode, the photoelectrons pass through a deflecting electric field which causes the photoelectrons to sweep across the anode. The deflecting electric field is created when a varying voltage is applied to the deflecting plates in the tube. The result is a two-dimensional signal, consisting of the temporal variation of the detected light reflected from the turbid medium in one dimension, and the lateral position of the reflected light over the narrow, fan-shaped pulse beam in the other direction. The focused electrons can be sensed directly by an area detector, such as a thinned backslide illuminated CCD, or the electron energy can be converted to light by a phosphor. The light emitted from the phosphor layer on the anode is coupled to a detector array.

A volume display of the medium is generated by translating the transmitter and receiver normal to the longitudinal axis of the fan-shaped pulse beam to illuminate adjacent sections of

the medium, and combining the sections to provide a volume display. All, or substantially all, of the light returned from each pulse is utilized to create three-dimensional data sets. The motion of the vehicle is used to provide the scan or motion of the fan-shaped pulse beam.

The present invention is not exclusively restricted to analyzing the contents of large volumes. By using very short pulses, picoseconds in duration for example, the present invention can be used to analyze smaller volumes. The streak tube observes the rapid return of the backscattered light by distributing the return in space and then reading the return out slowly. The return is in nanoseconds and picoseconds and the system of this invention allows a readout in milliseconds, thus obviating the necessity for faster electronic readouts. All of the signal from each pulse of the fan-shaped pulse beam width and depth that is back reflected is observed at once, avoiding the need to use a multiplicity of pulses to obtain three-dimensional information.

Normally, laser beams are non-uniform in intensity, with a maximum intensity at the center of the beam and a minimum intensity at the outermost edges of the pulse beam. This can be changed by applying tapered coatings to the laser mirrors, or by the use of optical means external to the laser. An optical invertor, comprised of a series of lenses and a diamond-shaped mirror arrangement, enhances the intensity at the outer portions of the pulse beam by optically inverting in one dimension along the fan width the intensity pattern of the pulse beam. The result is a pulse beam which compensates for the effect caused by longer paths at the ends of

the fan to produce a signal return that is substantially uniform in intensity.

FIG. **1** shows a typical configuration of an aircraft **10**, employing the present invention to detect underwater targets. The invention can also be used to detect targets in other turbid media, such as air. The invention can also be deployed from a vehicle such as a helicopter, a boat, or if searching at great depths, a submerged vehicle. A narrow, fan-shaped pulse beam **12** is projected from the transmitter to the water below, with the longitudinal axis of the pulse beam **12** normal to the direction of flight. The pulse beam **12** illuminates a thin section in the water. Coverage of a volume of the water is obtained by issuing a series of discrete pulse beams **16-18** to illuminate adjacent sections of the water. After processing the successive slice images, the sections can be displayed to show a scan through a volume of the medium. Thus, the motion of the vehicle carrying the system is used to provide the scan of the pulse beam. The pulse rate to generate the series of discrete pulse beams is set by the aircraft velocity. In general, the pulse rate may be high and the beam width on the water surface narrow compared to the resolution determined by the imagery detector pixels. This is done to preserve temporal resolution, which can be reduced if the spatial width becomes large. In order to reduce the number of readouts of the CCD, the pulses can be accumulated on chip.

FIG. **2** shows a block diagram of the preferred embodiment of the invention. A timing unit **20** initiates the probing sequence by causing a laser **22** to emit a narrow, fan-shaped pulse beam **12**

to illuminate a thin section in the water. After the Q-switch **84**, shown in FIG. **5**, in the laser **22** has closed, causing the laser to fire, the timing unit **20** initiates the variable delay unit **24**. The variable delay unit **24** issues a delay pulse **26** to initiate the receiving unit. In order to insure that the delay is correct, a detector **28**, such as a photomultiplier, is used to sense reflected portions **30** of the pulse beam. The timing unit **20** measures this time and resets the variable delay unit **24** to insure that the next delay pulse **26** is correct. Since the delay is variable, the invention can be operated at different aircraft altitudes.

The reflected portions **30** of the pulse beam are collected and focused on the photocathode **32** of a streak tube **34** by an optical element, shown here as a lens **36**. The image, which includes a wide spread of scattered light, is chopped by the field-limiting slit **126** which is aligned with the image of the fan-beam, and serves to reject scattered light as well as limit the width of the electron image to a width smaller than the temporal sampling obtained by the pixels in the imaging detector. A lens **125**, positioned between the field-limiting slit **126** and the photocathode **32**, reimages the image on the field-limiting slit **126** onto the photocathode **32**. The photoelectrons **110** emitted from the photocathode **32** are accelerated by the streak tube anode voltage, and are focused into a line on the anode **44** by the electrostatic or magnetic field distribution in the streak tube **34**, and are deflected by the electrostatic field set up between the deflection plates **40** and **42** in the streak tube **34**. In other words, one field forms the image, and the other field set up between the deflection plates **40** and **42**

moves the image. The delay pulse **26** initiates the action of a sweep generator **38**, which causes a linearly increasing voltage **43** and **45** to be applied to the deflection plates **40** and **42** on the streak tube **34**. The line electron image is deflected by the deflection plates **40** and **42** so that the line sweeps across the streak tube anode **44**, thus converting a temporal variation in the input signal into a spatial distribution on the anode **44**. The anode **44** may be made of a phosphor, but since there are few photoelectrons **110** from the return when the beam has penetrated many diffusion lengths in the water, additional photon gain is desired. Thus, the anode **44** is preferably made of a microchannel plate (MCP) intensifier, which provides the gain required to make photoelectrons **110** detectable. The electron output of the MCP is converted to photons again by means of a phosphor layer **46**, so that the image of the temporal variation over the narrow fan-shaped pulse beam **12**, now converted to a two-dimensional image, can be coupled to a detector array **48** by a coupling device, such as a lens **50**. Other coupling devices, such as a fiber optic, may be used. The detector array **48** shown is a CCD, but it could easily be a diode array, and, in particular, a photodiode n-channel MOSFET array or diode limited CCD that provides a logarithmic response to high light levels.

If the accelerating voltage is high, gain can be obtained through the ionization created by the electrons directly in the detector. Thus, the anode **44** can be made of a backside thin CCD fabricated for this purpose, and a MCP and phosphor are not required.

The CCD detector array **48** is set to

receive the image, before it arrives, by reading out the preceding frame. Once the sweep generator has completed the voltage rise and resets, a command is issued to the video control **52** to read the image on the CCD. The data is then passed to a processor **54**, or directly to a cathode ray tube display **56**, where a waterfall like display of the section of the ocean probed by the pulse beam **12** can be seen. Typical images are that of a water surface **58**, a reflecting object **60**, and a shadow from the reflecting object **62**.

The subsequent display of such ocean sections can be manipulated by adding many sections together to provide a volume display of the underwater scene. Specifically, the sensor system is moved normal to the longitudinal axis of the pulse beam **12** between each exposure to illuminate adjacent sections of the ocean. The adjacent sections are then combined to obtain a volume display.

As described, the present invention would only be able to probe deep depths at night because of solar illumination. For the system to operate in the day, narrow band interference filters **124** are required. The filters **124**, placed in front of the photocathode **32** of the streak tube **34**, are designed to pass the wavelength of the laser and block all other wavelengths. The combination of the filters **124** and the short time each element in the detector array **48** sees photoelectrons **110**, typically 5 nanoseconds thereby resolving 0.56 meter in depth, would insure that no more than a few background photoelectron count in any pixel would be obtained.

FIG. **3** shows a timing diagram of signals obtained from the reflected portions **30** of the pulse

beam. The time history of the reflected portions **30** of the pulse beam comprises a record of the reflection from the medium itself, and from any submerged bodies in the medium, such as mines or submarines, including the reflection from the top surface of such objects and of the shadow below them. Because the part of the ocean illuminated by the pulse beam **12** is limited to a very thin section, the image on the phosphor layer **46** is a wide vertical section of the ocean. The image can be photographed by means of a CCD camera or similar device, particularly by logarithmic area array CCD-like detectors, which read out slowly compared to the fast duration of the returning signal. Consequently, the phenomena on the cathode ray tube display **56** can be viewed directly, or the image can be processed by a processor **54** to obtain enhanced imagery after the signal has been encoded. For the latter, various common enhancement means, such as subtracting the mean return from the recorded ocean section, can be utilized.

In the regions of the pulse beam in which there are no objects, as shown in FIG. **3(a)**, there will be a sharp return from the air-water interface **64** and then a smaller exponential return from the backscatter from the water itself **66**. The signal will end with a second sharp return **68** from the bottom, assuming the system can reach such a depth. The range capability of the system will depend on the attenuation length of light in the medium traversed. For example, the attenuation length of light in water varies from 40 meters, for Jerlov Type I clear ocean water, to a few meters, for Jerlov Type C turbid bay water.

When the pulse beam encounters a submerged

object, as shown in FIG. **3(b)**, the reflected portions of the pulse beam will be typified by a sharp leading edge **70** which will vary over the width of the pulse beam due to the roundness of the object. Following the return will be a shadow **72**. Thus, the combination of the sharp leading edge **70** and the shadow **72** will comprise the signature of a submerged body.

In addition to detecting targets which are immersed or floating in the medium, the present invention also detects targets lying on the bottom of the medium. When the beam encounters an object on the bottom, as shown in FIG. **3(c)**, the system will detect a return from an object on the bottom **74** before it will detect a return from the bottom where no object is present **68**. Thus, with a profile of the bottom topography, silt covered objects, such as archaeological remains or mines lying on the bottom, can be distinguished from the bottom itself.

A diagram of the beam distribution on the MCP, phosphor and CCD is shown in FIG. **4**. The task of detecting the various components out of the return requires an analysis of the waveforms, such as those shown in FIG. **3(a) - 3(c)**, over the width of the fan. This analysis is enabled by the principle embodiment of the invention that utilizes the streak tube to present a spatial display of all parts of the fan beam as a map of position versus time, or depth.

The laser and the output projection optics are depicted in detail in FIG. **5**. The laser required for the lidar of this invention is a typical Q-switched laser that can produce pulse widths of the order of 5 to 15 nanoseconds. For purposes of illuminating the ocean and penetrating

it, wavelengths in the vicinity of 470 nanometers are optimum. In very turbid water, however, yellow matter reduces the penetration at this wavelength so that the optimum wavelength can be as long as 532 nanometers. Applicable lasers are doubled Nd-YAG, or Nd-YOS, Excimer lasers using the C- A transition in XeF, and Copper vapor. All of these can provide considerable power, in the order of joules/pulse at the reasonably high rates required for observations from aircraft. Diode pumped Nd-YAG for example could provide 1 joule at 30 Hz.

Shown in FIG. **5** is a typical diode pumped YAG laser, consisting of the YAG rod **74**, diode pumps **76** with a reflector **78**, and an output coupling mirror **80** forming the resonant cavity of the laser. The diode pumps **76** are driven by a diode driver **82** triggered by the timing unit **20**. When the rod **74** has been exposed to the pump energy and is maximally excited, the Q-switch **84** is opened and the lasing action sweeps through the excited states to produce an intense short pulse. These lasers commonly emit in the infrared, 1.06 micrometers. However, a nonlinear crystal in the path of the beam **86** can be arranged so that the frequency of the radiation is doubled to give the desired wavelength at 0.53 micrometers.

The output of the laser, for the energy levels required, will be a beam with a half width of 4-6 mm. The beam will be expanded so that it can cover a 5 by 1500 meter area on the ocean surface from a typical altitude of 1500 meters by means of an anamorphic optical element which has a focal length of -1.5 meters aligned with the flight direction. This would produce the 5-meter wide slice and a focal length of -7.5 mm in the other

direction to produce the 1000 m cross track illumination.

If the beam is gaussian **88**, an optical invertor can be used to enhance the intensity of the outer portions of the pulse beam. After the beam is directed downward by a mirror **90** and slightly diverged by lens **92** it arrives at a diamond-shaped mirror arrangement **94** which cuts it into two parts as shown by the dashed lines, and reflects it outward to a set of mirrors **96**, which return the beams to the central mirror arrangement **94**. Because the beams reflect from three mirrors, the parts of the beam that were outside **98**, and were the least intense, now fall at the inside of the beam **100**. In the same respect, the parts of the beam that were in the inside **102**, which were the most intense, now fall on the outside of the beam **104**. This results in an inverted intensity pattern which then compensates for the increased path length to the ends of the pattern and for the cosine losses on illumination and on the return, to provide a more uniform signal over the illuminated region.

FIG. **6** is a schematic diagram of the detection system with the preferred embodiment. The most important part of the detection system is the streak tube. Any of the existing and commercially available designs are applicable to the invention, but there are characteristics which make some streak tubes better than others. The important specifications are cathode size, resolution and speed.

The photocathode **32** should be as wide as possible to permit the use of a large light collecting optic. This is because the signal E that is collected by a detector element with an area A,

in an optical system with a numerical aperture n.a. is given by the equation,

$$E = \pi B(n.a.)^2 A \qquad (1)$$

where B = magnetic flux density

n.a. = $1/(2 \cdot f/\#)$, f = focal length.

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The brightness of the lidar return is given by the laser energy, and the highly attenuated scattering from the object, or the water. The numerical aperture of the light collecting optics is limited practically to 0.5, (f/1 optics), since the focal length f is equal to the aperture diameter. The only way to obtain an increased signal is to increase the detected sample area on the photocathode. For example, if a 30 mm long photocathode (which could be as narrow as the field-limiting slit) was used to cover 300 samples over 1500 meters of surface, the focal length of the optic could only be as large as 17 mm, and the aperture area to collect the return laser light would only be 2.2 cm^2, which is very small. Large photocathodes, however, are available in X-ray imaging tubes and scintillation detectors, and electron optics are capable of imaging the photoelectrons. At present, there are intensifier tubes with S-20 300 mm photocathodes which would permit light collecting optics with aperture areas as great as 220 cm^2 to be used. These intensifier tubes have a signal strength 100 times greater than the signal strength of smaller, more readily available, tubes. Thus, the possibility of building or obtaining a large streak tube which would utilize the electron optics of larger intensifiers is well within the state of the art.

In order to view a 1500-meter swath width, the resolution of the streak tube should be

sufficient to permit observing 300 samples in width and time. Moreover, to view depths of 150-300 meters, a streak tube should have 5-10 nanosecond resolution.

Even with a photocathode **32** as large as 300x1 mm, as shown in FIG. **6**, the final image can be placed on a CCD as small as 7.5x7.5 mm. (Standard CCD size is 6.6x8.8 mm.) The light **30** from a fast large aperture light collecting optic **36** (f/1, 170 mm focal length), shown in FIG. **2**, focuses on the fiber optic input window **106** and passes to the photocathode **32**. The extraction electrode grid **108** accelerates the emitted photoelectrons **110** which are focused on the phosphor layer **46** by the focus electrodes **112**. A varying voltage **40** on the deflection plates **40** and **42** causes the position of the photoelectron beam **110** to change rapidly, giving an output whose intensity versus distance is proportional to the input intensity versus time.

At the phosphor layer **46**, the photoelectrons **110** are converted to photons, with some gain due to the accelerating voltage. The photons are then coupled to a second photocathode **114** at the input of an image intensifier consisting of microchannel plates (MCP's) **116**. This permits the event to spread over the MCP structure to reduce the poor noise factor caused by wide pulse shapes and losses in pore structures that degrade typical MCP performance. At the output of the MCP's **116**, a second phosphor layer **118** converts the photoelectrons to photons. The size of the second phosphor layer **118** and the MCP's **116** is about 40 mm, thus permitting a 30x30 mm image area. Typical dynamic electron optic resolutions and MCP resolutions are of the order of 10 lines/mm.

The last part of the detection system is the coupling of the second phosphor layer **118** to the detector array **122**. Coupling to the CCD is often done by a lens **50**, as shown in FIG. **2**, or by a fiber optic coupler. The demagnification required is about the same in both cases, as is the loss in gain of 16 that is the result of a 4x reduction to typical 6.6x8.8-mm CCD's containing 25-micrometer photodetectors.

Commercially available streak tubes have photocathodes up to 30-mm in diameter, output phosphors up to 44 mm in diameter, and may have built-in MCP's. Speed and resolution are compatible with the specifications given above.

While this invention has been described with reference to its presently preferred embodiment(s), its scope is not limited thereto. Rather, such scope is only limited insofar as defined by the following set of claims and all equivalents thereof.